EXPERIMENTAL INVESTIGATION ON A GEOCONTAINER SUBMERGED REEF

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Abstract

Geotextile sand containers (GSC) have been used as permanent construction elements in coastal works for more than 20 years, becoming more and more popular as an alternative to the most typical coastal structures. Aim of this work is to analyze the hydrodynamic, stability and morphodynamic response of a GSC submerged reef by means of an experimental campaign. The first investigated aspect concerned the hydrodynamics. The reflection and transmission coefficients for regular and random waves were determined: the reflection coefficient decreases with increasing of kh; the transmission coefficient decreases with the increase of the incident wave. As regards the stability of the structure, it was observed that the strongest waves were able to lift the row of GSC more exposed to the wave action. An instability curve for the GSC as a function of the hydrodynamic characteristics was then found. Flow visualization close to the reef was performed by means of ink, showing that the flow becomes asymmetric in the proximity of the structure. Concerning the morphodynamics, long-term tests were performed to calculate the scour. This reached its maximum value at the end of each test and it is present in all three cases. The scour causes serious problems of instability to the structure.

Keywords: Submerged Reef; Geotextile Sand Container; Coastal structures; Morphodynamics; Scour processes.

1.Introduction

Over the last twenty years, the extreme human settlement in coastal areas and the construction of hard structures near the coasts led to serious consequences such as coastal erosion and flood risk. Today, it is increasingly urgent to give an effective response to the problem of beach protection from wave attack. Beach nourishment protected at the toe by submerged reefs represents a low-impact mitigation work to ensure an adequate protection to the litoral areas. Despite the popularity of such engineering solution, little attention has been paid in analyzing hydro-morphodynamics of protected beach nourishment (Faraci et al., 2014), while, on the other hand, there are numerous studies both on the evolution of beach profiles and on the effectiveness of submerged barriers (Van der Meer, 1988; Burcharth et al., 2006). Furthermore, the research of materials and solutions that combine versatility and economy is even more relevant. An interesting solution is represented by the use of Geotextile Sand Containers (GSC) for the realization of mixed coastal defences at low costs, especially when compared with the more traditional rubble mound structures. The great advantage of such solution is the possibility to use sediments to fill the geocontainers, thus avoiding the exploitation of terrestrial caves, as well as reconsidering the filling material as a resource rather than a waste. The GSC have been used as a coastal protection in different parts of the world. For example in South Africa Corbella and Stretcha (2012) observed that for a greater stability of the barrier, the slope of the containers should be 45°. Shin and Oh (2007) showed the beneficial effects due to the use of a geotextile tube system in Korea. In particular they performed a comparison between field measurements and hydraulic model tests, demonstrating the ability of the structure to the wave absorption. They also noticed that the rapid construction is an obvious positive aspect of this innovative technology also from an economical point of view. Shin and Oh (2007) observed the appearance of algae on the submerged surface after one year since the implementation of the GSC, thus implying a positive effect on marine life balance. Furthermore, being the east coast of Korea exposed to various severe storms , the reef stability was also proved.

Koerner and Koerner (2006) analysed four different geotextiles and their interaction with three different filling materials, processing the several GSC to “hanging bag test” HBT tests. They found that the flow rates were directly proportional to the permeability of the soil contained within the tube and that the behaviour of geotextile bags was not dependent on conventional parameters. Later on, Oumeraci and Recio (2007) concerning the geotextile barrier permeability, found that the permeability of a GSC structure depends mainly on the size of the holes between the bags. Oumeraci and Recio (2008), who investigated the hydrodynamic response of a GSC structure with different placements of the geotextile sand bags, found that a random placement instead of a longitudinal one accomplishes a higher permeability; however the hydraulic stability for surface piercing structures is compromised. The sand fill ratio, the type of geotextile material and the interface friction between GSCs affect different processes governing the hydraulic stability of GSC-structures. Dassanayake and Oumeraci (2012) systematically quantified the effects of the engineering properties and the slope of GSCs on the hydraulic stability and they determined the sensitivity of each GSC property versus he hydraulic stability, presenting new hydraulic stability nomograms, including implications for the engineering practice.

Following these pioneering experiences, this work reports some preliminary considerations concerning the hydrodynamic, stability and morphodynamic response of a GSC structure.

2.Experimental set-up

The experiments have been carried out at the Hydraulics Laboratory of the University of Messina in a wave flume 18 m long. The channel has a rectangular cross section 40 cm wide and 80 cm high. The vertical walls are made of glass plates suitably fixed on a metal frame for the entire length of the channel (Figure 1).

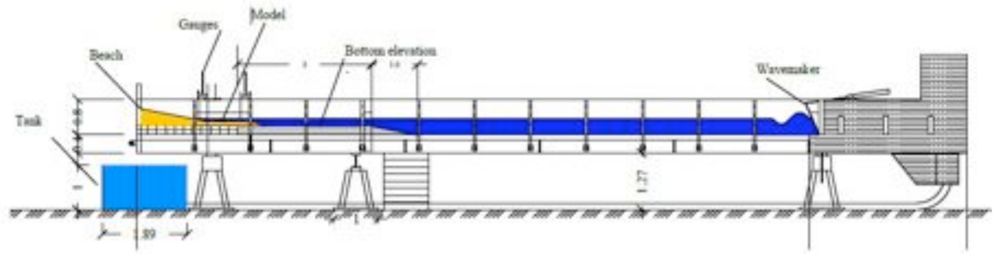


Figure 1 Sketch of the wave flume.

The flume has a tilting bed and an external recirculating system fed by a 11 kW centrifugal pump, and it can be suitably used also for steady flow tests. It is held by two supports: the first, located approximately 3 m far from one end of the flume, is an hydraulic piston that allows the slope of the channel to be set, the other support, 10 m far from the first, is a hinge fulcrum. In the present paper it has been kept in an horizontal configuration, and a third support has been added for safety reasons, at a 3.5 m distance from the second one. A flap-type wave maker is driven by a pneumatic system and electronically controlled. Both regular and random waves can be reproduced. Regular waves are controlled by a control panel that allows frequency, amplitude and offset position of the signal to be set, while random waves are generated through a software which is able to reproduce a Jonswap spectrum with a peak enhancement factor of 3,3. In this case a time series of 3 minutes was generated and then identically repeated for all the test duration. At the back of the wavemaker some mattresses of creased pipe pieces have been located with the aim to absorb any spurious reflection caused by the flap. At the opposite end of the channel the physical model of a GSC reef has been realized as it is better described in the following.

For the measurement of the wave heights in the channel, four resistive level probes, 300 mm long, made of two metal wires of stainless steel of 1.5 mm diameter, arranged in parallel at a distance of 12.5 mm, have been employed. The four gauges were named s_1, s_2, s_3 and s_4, starting from the wave maker in the direction of the wave motion. Three of them were placed offshore the reef, with the purpose of evaluating the incident and the reflected wave components making use of the Mansard and Funke (1980) method. The last one was placed onshore the sill to evaluate the transmitted wave energy.

The submerged reef was built with geotextile sandbags. Models of sandbags were made with a 1:50 model to prototype scale ratio (Figure 2).

Figure 2 Picture of the geocontainer submerged reef model that was adopted in the present experimental campaign.

Each GSC was realized by making first: the geotextile casing, which was left open by one for the filling operations. It was then filled with sand characterized by a mean grain size d_{50}= 1.4 mm sand and finally the last side was closed, making sure to verify the size of the model. Each GSC weighted 320 g at a model scale. 80 GSC were made and the model of the submerged reef was built as shown in Figure 2. Table 1 shows the geometric characteristics of the structure, respectively, at a prototype scale and at a model scale. More exactly, the length of the bags in the direction of the wave motion is indicated with l_c , while the width of the bags in the transverse direction is indicated with b_c and the height of the bags with h_c.

Table 1 Geometrical dimensions out a prototype and models scale of GSC.

		Prototype	Model
l_c	(m)	7.5	0.15
b_c	(m)	4	0.08
h_c	(m)	1.5	0.03

A HD video camera and a camera were used in order to record each step of the work along with the dynamic evolution of the performed tests.

3. Experimental results and discussion

Aim of the work has been to investigate the response of the GSC structure in terms of:

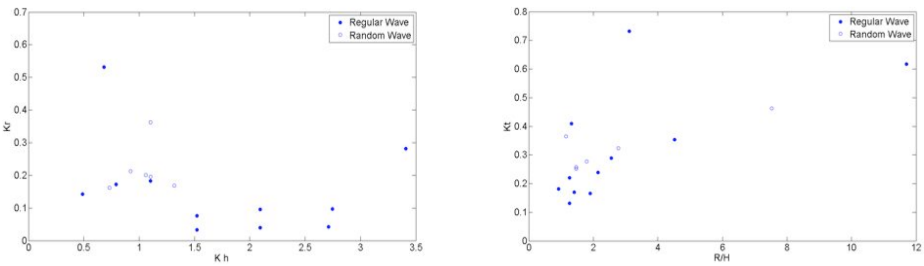
•Hydrodynamics

•Stability

•Morphodynamics

The first aspect investigated in the experimental campaign concerned the hydrodynamics. The reflection and transmission coefficients for regular and irregular waves were determined. Several methods for estimating wave reflection in laboratory facilities have been presented in the literature, regular waves (Isaacson, 1991) and random waves (Thornton and Calhoun, 1972; Goda and Suzuki, 1976; Mansard and Funke, 1980). In the present work the Mansard and Funke (1980) method has been used.

As observed in Figure 3a), the reflection coefficient, plotted as a function of the relative depth kh (k being the wave number $2\pi/L$, L the wavelength and h the water depth), decreases with increasing of kh, attaining values generally lower than 0.2 for kh between 1.2 and 3. The wave transmission through the reef was also evaluated. The results are plotted as a function of the ratio of the submergence R to the incident wave height H_i. The transmission coefficient decreases with the increase of the incident wave (Figure 3b). The smaller waves are not affected by the presence of the reef , thus waves are fully transmitted at the back of the reef. The attenuation of the incident wave becomes evident for R/H values smaller than 4; here the transmitted wave is smaller than about 40% of the incident one.



(a) (b)

Figure 3 a) Reflection coefficients b) Trasmission coefficients.

During the execution of these tests it was observed that the stronger waves were able to lift the GSC row more exposed to the wave action. In order to investigate this aspect a series of experiments was performed by keeping the period constant and changing the wave height till the instability of the first row was observed. This procedure was followed for several wave periods and two different water depths, namely h_1= 22 cm - h_2 =24 cm. The results of these tests are reported in Figure 4 where the non dimensional incident amplitude A_i, made non dimensional by means of water depth was plotted as a function of non dimensional period $T/(gL)^{0.5}$. In the plot the tests that showed an instability of the GSC are distinct from those for which the stability was not compromised.

Looking at Figure 4 it is noted that a curve was found that separates two distinct:

$$A_i/h = 0.0001 / (T/(gL)^{0.5}-0.28)+0.068; \quad [1]$$

In the area above the curve described by Eq. [1] there is instability of the GSC, while under the curve the

GSC are stable: in this area the geotextile containers do not move and the stability of the reef to the wave action is not compromised.

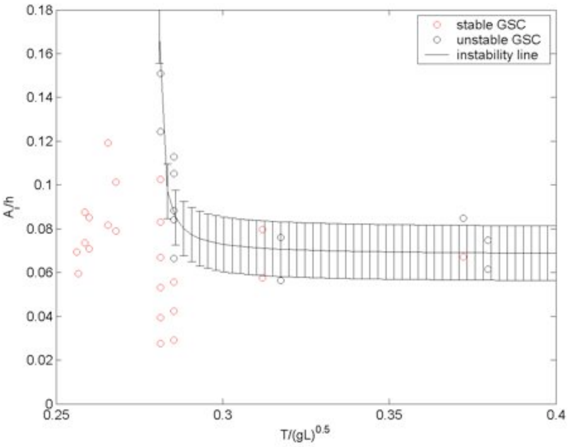


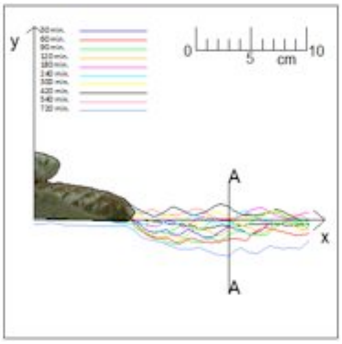
Figure 4 GSC instability curve as a function of hydrodynamic characteristics.

To study the wave-structure interaction, colored ink was also spilled in the channel with a needle (Figure 5). The needle was positioned 3 cm offshore from the GSC and 2.5 cm below the still water level. The test was done with a wave of H_i = 3 cm and T = 1 sec at a model scale. The ink showed the classic elliptical particles of fluid profile under the wave crest and the overall movement of the water flow, pushed by the wave, towards the reef structure. Under these conditions the ink is transported by the wave in the offshore direction for about 2/3T and for about 1/3T in the onshore direction. Clearly the time is subject to the error of the operator. This information shows that for this wave condition close to the reef the flow becomes asymmetric. The ink showed also that the water seeping under the bags exerts an upward thrust on the GSC, exactly when the crest of the wave passes, causing instability and accumulation of sand in the gaps of the structure.

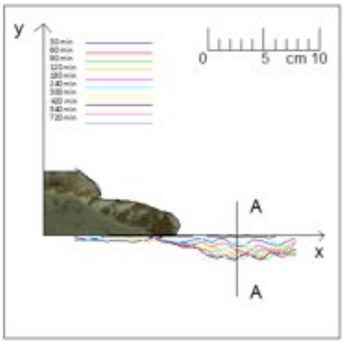
Figure 5 Test with coloured ink.

The next step was to force the GSC barrier with 12h long wave series, corresponding to a storm of about 85 hours at a prototype scale. Three tests were performed, the first with regular waves with H_i= 3.6 cm and T 1 s, in the following referred to as test001, the second one with random waves with H_i=1.8 m and T=1 s, indicated as test002, and the third with regular waves with H_i=4.6 cm and T=1 s, namely test003. For test003 colored sand was also used to investigate the movements of the sand offshore the structure and through it.

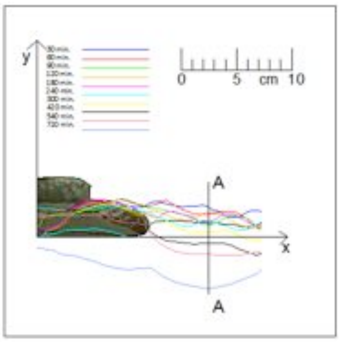
Beach profiles were plotted for all three tests after 30 min, 60 min, 90min, 120 min, 180 min, 240 min, 300 min, 420 min, 540 min, 720 min from the beginning (Figure 6). Then, the scour at the reef toe was also measured (Figure 7). In the test001 (Figure 6 a)) initially the material is transported offshore and determines a scour at the toe of the reef (t=0-90min), after that it accumulates near the reef (t=90-420 min), and than it reaches the maximum scour at the end of the test, i.e. after 12 hours. In the case of random wave test002 (Figure 6 b))the scour reaches its maximum value at 540 min and then it basically remains constant until the end of the test. In this case it is also visible that the sand reaches an equilibrium profile that is maintained till the end of the test. The scour causes serious problems of instability of the structure. In the case of random waves scour takes place since the beginning of the test (30 min.) (Figure 6 b)). In test003 the scour at the reef toe was also measured (Figure 6 c). During the tests initially the material accumulates near the reef (t=0-180 min), after that it is transported offshore and determines a scour at the toe of the reef. The maximum scour is reached at the end of the test, i.e. after 12 hours. In both the cases of regular waves test001 and test003, the scour at the toe occurs after a longer time, but it is more severe (Figure 6 a) and c)). The results are synthesized in Figure 7, where the scour evolution, made non dimensional with the maxim scour, is reported.



(a)



(b)



(c)

Figure 6 Beach profiles at the toe of the structure: a) Regular wave Hs = 3.6 cm b) Random wave Hs= 1.8 cm c) Regular wave Hs = 4.6 cm.

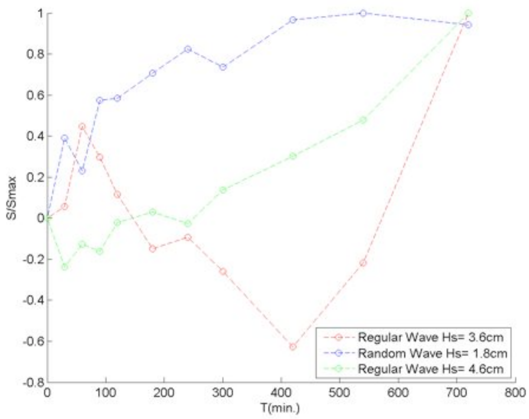


Figure 7 Non dimensional scour evolution.

As said before, in the test003 the upper 3 cms of sand were replaced with colored sand. Once colored, the sand was prepared in strips of a width of about 5 cm in yellow, blue, red and green. To prevent the mixing of different color sand, during the tests a separator plate was used, as shown in Figure 8.

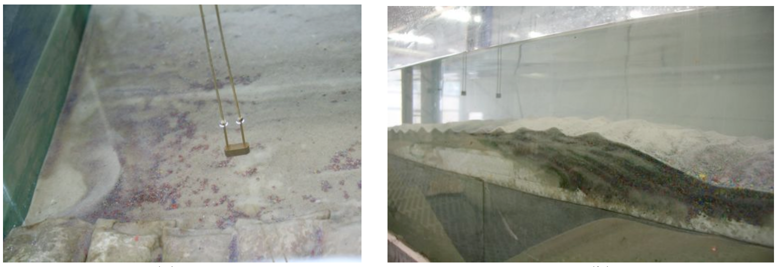
Figure 8 Installation of coloured sand

The test003 more clearly illustrates the sediment transport processes. After the first three hours of experiment, the amount of sediment entrained in the barrier is significantly higher than the outgoing amount (almost absent). After 180 minutes, the red and the blue sand overcame the yellow sand and after some time they led to an accumulation inside the reef. (Figure 9) The green sand was mainly transported offshore towards the wave maker and only in a small part towards the other three colored layers. Moreover the first row of geotextile bags was completely submerged by the sand, while the second row was partly covered by sand. This may affect the response of the barrier to the wave: the beach slope changed leading to an anticipation of the wave breaking. Moreover the permeability of the structure completely differed from the initial one, as the sand occupied almost all the space between bags.

Figure 9 The red and the blue sand overcame the yellow layer (t=003min).

After the first three hours the yellow sand (Figure 10),which was completely submerged by red and blue sand, (t=300min) is now visible, because the material that was accumulated over it and over the first and second rows of bags was transported in part towards the interior of the barrier, up to determine small accumulations over the structure itself (beach side) (Figure 11a), and partly offshore (Figure 11b). This is clearly a beneficial effect in response to coastal erosion in on-shore side.

Figure 10 The model at t=300min.



(a) (b)

Figure 11 a)small accumulations over the structure (beach side) b) the material offshore(t=720min).

The mass of sand transported towards the wave maker (t=720 min) is of different color, red, green and blue and it tries to achieve an equilibrium profile. This trend was noted up to 10 hours from the beginning of the of test, while from to 500min. until the end of the test (t=720min), an interesting aspect was revealed, as the cluster of colored sand, now including all four colours, was transported offshore, removing completely the sand that at the beginning overlapped the first two rows, thus creating a strong action of excavation at the toe of the structure. (Figure 12) This effect caused a serious instability.

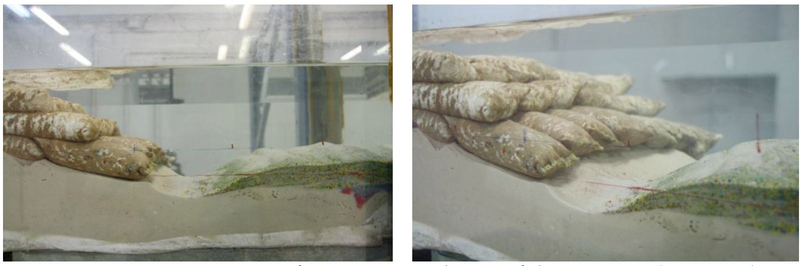


Figure 12 A strong action of excavation at the toe of the structure (t=720min).

After the test completion, the reef has been disassembled to assess the quantity of material left inside the structure (Figure 13). The significant accumulation of sand inside the barrier could affect the effectiveness of the work of it. Indeed the decrease of the structure permeability may led to different hydrodynamic conditions that affect the reflection and transmission coefficients.

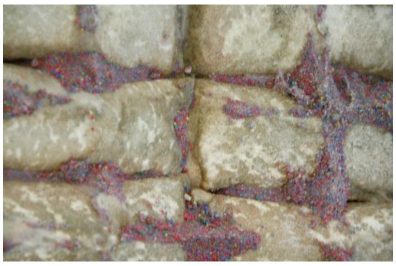


Figure 13 Sand entrained inside the structure.

The analysis of the profiles of the three tests revealed that the barrier modifies the wave and consequently influences the sediment transport at the bottom. The protected beach has an advantage from the presence of the barrier, because the tests showed no erosion, but rather small sand deposits. The offshore side of the barrier shows some instability problems, as mentioned. The regular waves of test001 and test002 cause a strong scour at the toe of the barrier and also the sandy bottom does not seem to reach an equilibrium when running tests with regular waves. This causes the continuous movement of material and this also affects the wave, in particular changing the breaker line. In the case of test003 with irregular waves the sandy bottom reaches an equilibrium profile. This is an advantage for the stability of the barrier because it limits the scour at the toe and the offshore sediment transport.
These tests were useful to find out how the reef influences the sediment transport across it. In particular the reef, subjected to a storm, responds very well in terms of beach protection; indeed the protected beach is not affected at all by the erosive action of the waves. On the contrary a small percentage of solid material coming from the offshore has been found onshore. On the offshore side, the barrier is subjected to a cyclic behaviour of the sediments that, trying to reach an equilibrium profile, in a first time, submerge the structure determining a change in the barrier slope and permeability and, in a second moment, the opposite happens, as a strong scour at the toe has been observed.

4.Conclusion

In this work an experimental campaign was carried out in order to contribute at understanding the effects of a non conventional submerged reef made of geotextile sand containers to the nearshore hydro-morphodynamics. Measurements of both reflection and transmission coefficients for the reef, realized at a 1:50 model to prototype scale were performed. The reflection coefficient attained values generally lower than 0.2, for kh between 1.2 and 3.The transmission coefficient decreased with the increase of the incident wave and, for R/H values smaller than 4, the transmitted wave was about 40% smaller than o the incident one.
Another objective of the work was to verify the stability of the reef. A little instability due to the lifting of the bags caused by the more energetic waves occurred. A chart that provides important information

about the lift of GSC as a function of the period of the wave was illustrated. This could be an useful indicator for assessing engineers during the design stage.

The morphodynamics was another investigated topic. 12 hours long tests for both regular and random waves were performed. The sediment transport for regular and random wave tests behaved differently. In the random wave test the scour at the toe was smaller than in the regular waves one. The regular wave tests showed how the presence of the barrier affected the sediment transport, causing an offshore sand loss, with consequent serious scour at the toe and possible stability problems for the reef itself.

Acknowledgements

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